Issued August 24, 1914.

HAWAII AGRICULTURAL EXPERIMENT STATION,

E. V. WILCOX, Special Agent in Charge.

Bulletin No. 35.



# ABSORPTION OF FERTILIZER SALTS BY HAWAIIAN SOILS.

BY

WM. McGEORGE,

ASSISTANT CHEMIST.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

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## HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

### STATION STAFF.

E. V. WILCOX, *Special Agent in Charge.*
J. EDGAR HIGGINS, *Horticulturist.*
W. P. KELLEY, *Chemist.*
C. K. MCCLELLAND, *Agronomist.*
D. T. FULLAWAY, *Entomologist.*
WM. MCGEORGE, *Assistant Chemist.*
ALICE R. THOMPSON, *Assistant Chemist.*
C. J. HUNN, *Assistant Horticulturist.*
V. S. HOLT, *Assistant in Horticulture.*
C. A. SAHR, *Assistant in Agronomy.*

# LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *September 29, 1913.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 35 of the Hawaii Agricultural Experiment Station, a paper on the Absorption of Fertilizer Salts by Hawaiian Soils, by William McGeorge, assistant chemist. In order to be in position to recommend a rational program for the management of Hawaiian soils it has been found necessary to make a study of all the properties of these soils. In the present paper many interesting points are brought out upon the subject of the fixing power of these soils for different fertilizer salts. It appears that the concentration of a soil solution depends perhaps more upon the fixing power of the soils than upon the solubility of the salt.

Respectfully,

E. V. WILCOX,
*Special Agent in Charge.*

DR. A. C. TRUE,
*Director Office of Experiment Stations,*
*U. S. Department of Agriculture, Washington, D. C.*

Recommended for publication.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON, *Secretary of Agriculture.*

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# ABSORPTION OF FERTILIZER SALTS BY HAWAIIAN SOILS.

In undertaking investigations on soil fertility it is very necessary to have some knowledge of the absorptive or fixing power of a soil, since this factor is one of prime importance in the successful use of fertilizers and varies greatly with the physical structure, the organic matter content, and other factors of a chemical and biological nature.

## OBJECT OF WORK.

The object of the work here presented was to give some understanding of the absorptive power of Hawaiian soils for fertilizer salts. These soils contain an abnormally high percentage of iron and aluminum compounds, and from their physical condition would be expected to have a high fixing power. Many of the soil types of the islands also contain large amounts of organic matter and humus. J. T. Crawley[1] carried on some experiments with Hawaiian soils to determine the effect of irrigation upon added fertilizer salts. He found phosphoric acid to be firmly fixed, while ammonium sulphate and potassium sulphate were not so strongly fixed.

## SOIL TYPES USED.

Soils representing in a general way the important types of the islands were selected for the work. The following table shows the chemical composition of the soils, as determined by digestion in hydrochloric acid of specific gravity 1.115:

*Composition of soils used in the experiments.*

| Constituents. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Soil No. 517. | Soil No. 518. |
|---|---|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Moisture | 7.65 | 15.00 | 14.95 | 13.59 | 3.54 | 3.97 |
| Volatile matter | 8.42 | 25.58 | 22.24 | 20.01 | 13.71 | 13.56 |
| Insoluble matter | 38.49 | 15.10 | 34.99 | 33.77 | 41.99 | 41.53 |
| Ferric oxid ($Fe_2O_3$) | 16.63 | 19.20 | 8.24 | 7.00 | 21.76 | 21.46 |
| Alumina ($Al_2O_3$) | 12.85 | 16.64 | 10.73 | 16.79 | 17.23 | 18.21 |
| Titanium oxid ($TiO_2$) | 2.00 | 4.20 | 3.20 | 1.80 | ........ | ........ |
| Manganese oxid ($Mn_3O_4$) | .24 | .06 | .20 | .07 | .12 | .04 |
| Lime (CaO) | 1.84 | .50 | 1.91 | 3.80 | .36 | .20 |
| Magnesia (MgO) | 8.71 | 1.80 | 2.24 | .85 | .32 | .24 |
| Potash ($K_2O$) | .39 | .15 | .24 | .72 | .54 | .66 |
| Soda ($Na_2O$) | 1.36 | .68 | 1.40 | .10 | .23 | .46 |
| Sulphur trioxid ($SO_3$) | .08 | .53 | .45 | .45 | .58 | .52 |
| Phosphoric acid ($P_2O_5$) | .57 | .29 | .22 | 2.18 | .13 | .16 |

[1] Jour. Amer. Chem. Soc., 24 (1902), p. 1114; 25 (1903), p. 47.

Soil No. 292. This type of soil occurs in the lowlands in and about Honolulu, now being used for growing bananas, rice, and for truck farming. It has a sandy texture, being partly derived from black or volcanic ash. It has a grayish-brown color, abnormally high magnesia content, and low content of organic matter.

No. 448 represents the type of yellow clay scattered throughout the islands, this sample being taken near Hilo, Hawaii.

No. 428 is a dark colored, highly organic soil from Glenwood, Hawaii. It has a very sandy texture, is subject to heavy rainfall, and is rather unproductive.

No. 474 is a sample of soil from Parker ranch, Waimea, Hawaii. It is a brown-colored soil of floury texture and very productive.

No. 517 represents the type of soil which is most abundant in the islands, namely, the heavy red clay, a highly ferruginous type.

## METHOD.

The method of treatment adopted in this investigation was as follows: 100 grams of air-dry soil was placed in glass tubes, 1 inch in diameter, and fitted with rubber stoppers and pinchcock to regulate the passage of the solution through the soil. The percolation was regulated to flow at a rate of 100 cubic centimeters in 24 hours, and each successive 100 cubic centimeters of percolate was analyzed. The salts used were sodium nitrate, potassium phosphate, and calcium phosphate, separately and as a mixture. One series was also heated to 230° C. and another treated with chloroform to determine the effect of these agents upon absorption. All determinations were made by colorimetric methods, except those of potash, which was precipitated and weighed as potassium chloroplatinate.

## ABSORPTION OF PHOSPHORIC ACID.

In this series the percolation was carried on for nearly two months, 5 liters of the solution of potassium phosphate passing through the soil. The solution used contained about 200 parts phosphoric acid ($PO_4$) per million, and each time a new solution was made up the strength was determined by analysis. Owing to the fact that percolation through a column of the soil was found to be impossible, due to the strong deflocculating effect of this salt, the percolation in this series was carried on in funnels. Even then several of the samples filtered very slowly. The filtrate from the clay soil was very cloudy, and the percolates became slightly stagnant in several instances after the percolations had been carried on for about one and a half months.

In order to get a clear conception of the fixation of phosphates it is necessary to have some idea of the solubility of phosphoric acid already present in the soil when treated in the same way as in the

experiments. For this purpose the glass tubes were filled with 100 grams of soil, covered with distilled water, and each 100 cubic centimeters of filtrate analyzed.

*Phosphoric acid removed from the soils by distilled water.*

[Expressed in parts per million of $PO_4$ in the percolate.]

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|---|---|---|---|---|
| 100.......... | 6.4 | 3.2 | 3.8 | 3.8 | 500.......... | 5.6 | 2.8 | 4.6 | 7.0 |
| 200.......... | .......... | .......... | 4.4 | 4.4 | 600.......... | 11.2 | 2.0 | 4.4 | 10.8 |
| 300.......... | 8.8 | .......... | .......... | .......... | 700.......... | 12.0 | 2.0 | 6.0 | 5.2 |
| 400.......... | 3.8 | .......... | 3.2 | 5.0 | 800.......... | 10.8 | 3.6 | 20.0 | 11.2 |

The general tendency of these soils is to yield a solution of fairly constant concentration. This is in direct harmony with what should be expected, namely that the phosphoric acid is so firmly retained by Hawaiian soils that the first leachings should not yield a more concentrated solution than those following.

The following table shows the absorbing power of the soil for phosphoric acid in monopotassium phosphate ($KH_2PO_4$):

*Absorption of phosphoric acid from a solution of monopotassium phosphate* ($KH_2PO_4$).

[Expressed in parts per million of $PO_4$ in the percolate.]

SOLUTION CONTAINED 175 PARTS PER MILLION $PO_4$.

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|---|---|---|---|---|
| 100.......... | 45.6 | 13.6 | 11.2 | 17.2 | 2,100.......... | 62.8 | 4.0 | 5.2 | 25.6 |
| 200.......... | 35.2 | 29.0 | 13.2 | 40.0 | 2,200.......... | 60.0 | 5.2 | 4.8 | 38.4 |
| 300.......... | 52.0 | 10.4 | 17.2 | 44.0 | 2,300.......... | 60.0 | 4.0 | 4.0 | 22.4 |
| 400.......... | 38.0 | 13.6 | 34.0 | 49.0 | 2,400.......... | 66.4 | 5.6 | 6.0 | 22.4 |
| 500.......... | 39.0 | 9.6 | 19.4 | 36.0 | 2,500.......... | 62.8 | 4.8 | 4.8 | 31.2 |
| 600.......... | 48.0 | 11.2 | 15.6 | 39.0 | 2,600.......... | 56.0 | 4.8 | 4.8 | 16.8 |
| 700.......... | 57.0 | 15.6 | 16.8 | 42.0 | 2,700.......... | 44.0 | 4.0 | 4.8 | 32.0 |
| 800.......... | 27.0 | 36.0 | 36.0 | 55.0 | 2,800.......... | 28.8 | 4.0 | 4.8 | 28.8 |
| 900.......... | 20.0 | 5.8 | 20.8 | 35.6 | 2,900.......... | 31.2 | 3.6 | 4.0 | 35.2 |
| 1,000.......... | 17.8 | 5.8 | 27.8 | 41.6 | 3,000.......... | 39.2 | 4.4 | 4.4 | 32.0 |
| 1,100.......... | 71.2 | 5.2 | 12.0 | 24.8 | 3,100.......... | 21.6 | 4.0 | 4.0 | 24.0 |
| 1,200.......... | 37.2 | 6.8 | 13.2 | 40.0 | 3,200.......... | 6.8 | 5.6 | 5.6 | 26.4 |
| 1,300.......... | 72.0 | 6.4 | 14.0 | 34.4 | 3,300.......... | 33.6 | 5.6 | 5.6 | 44.0 |
| 1,400.......... | 60.0 | 10.0 | 16.8 | 20.8 | 3,400.......... | 25.6 | 10.0 | 29.6 | 36.8 |
| 1,500.......... | 76.0 | 7.2 | 12.0 | 52.0 | 3,600.......... | 20.8 | 8.0 | 8.8 | 29.6 |
| 1,600.......... | 72.0 | 5.6 | 11.6 | 56.0 | 3,800.......... | 46.6 | 10.0 | 9.6 | 31.2 |
| 1,700.......... | 42.0 | 13.6 | 12.0 | 24.0 | 4,000.......... | 29.6 | 4.4 | 6.4 | 34.4 |
| 1,800.......... | 64.0 | 9.6 | 8.0 | 20.0 | 4,200.......... | 46.4 | 5.2 | 12.4 | 48.0 |
| 1,900.......... | 66.4 | 4.4 | 4.4 | 18.0 | 4,400.......... | 34.4 | 4.8 | 8.0 | 48.0 |
| 2,000.......... | 54.4 | 4.0 | 4.0 | 14.8 | | | | | |

SOLUTION CONTAINED 140 PARTS PER MILLION $PO_4$.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4,600.......... | 40.0 | 6.0 | 7.6 | 24.0 | 5,000.......... | 34.4 | 4.0 | 4.0 | 24.0 |
| 4,800.......... | 24.8 | 6.8 | 8.4 | 23.2 | | | | | |

*Summary of above table.*

| Soil No. | $PO_4$ added to 100 gm. soil. | $PO_4$ fixed by 100 gm. soil. | Per cent of $PO_4$ fixed. |
|---|---|---|---|
| | *Gram.* | *Gram.* | |
| 292.......... | 0.8540 | 0.6872 | 80.6 |
| 448.......... | .8540 | .8146 | 95.5 |
| 428.......... | .8540 | .7977 | 93.3 |
| 474.......... | .8540 | .6882 | 80.7 |

The amount of phosphoric acid fixed from a solution of monocalcium phosphate ($CaH_4(PO_4)_2$) is shown in the following table:

*Absorption of phosphoric acid from a solution of monocalcium phosphate ($CaH_4(PO_4)_2$).*

[Expressed in parts per million of $PO_4$ in the percolate.]

SOLUTION CONTAINED 232 PARTS PER MILLION $PO_4$.

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 40.0 | 10.4 | 9.6 | 24.8 | 500 | 33.0 | 16.0 | 15.2 | 39.0 |
| 200 | 24.0 | 7.2 | 9.2 | 18.4 | 600 | 17.2 | 11.6 | 11.2 | 19.2 |
| 300 | 23.2 | 10.8 | 8.0 | 22.4 | 700 | 13.6 | 11.6 | 10.4 | 16.8 |
| 400 | 50.0 | 14.0 | 14.4 | 41.0 | | | | | |

SOLUTION CONTAINED 220 PARTS PER MILLION $PO_4$.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 800 | 11.6 | 11.6 | 11.2 | 14.4 | 1,200 | 14.4 | 6.0 | 6.4 | 11.6 |
| 900 | 15.6 | 4.4 | 6.4 | 11.2 | 1,300 | 18.4 | 4.0 | 8.4 | 13.6 |
| 1,000 | 24.0 | 4.0 | 4.8 | 21.2 | 1,400 | 28.8 | 5.2 | 10.0 | 17.2 |
| 1,100 | 30.4 | 4.8 | 6.0 | 21.6 | 1,500 | 17.6 | 4.4 | 8.0 | 21.6 |

SOLUTION CONTAINED 132 PARTS PER MILLION $PO_4$.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1,600 | 44.0 | 4.4 | 4.0 | 21.6 | 2,000 | 22.4 | 4.0 | 4.0 | 16.8 |
| 1,700 | 22.4 | 4.0 | 5.6 | 14.4 | 2,100 | 21.6 | 5.2 | 7.2 | 16.8 |
| 1,800 | 17.6 | 4.0 | 8.0 | 15.2 | 2,200 | 35.2 | 5.6 | 6.4 | 17.6 |
| 1,900 | 17.6 | 4.8 | 7.6 | 14.4 | | | | | |

SOLUTION CONTAINED 200 PARTS PER MILLION $PO_4$.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2,400 | 36.0 | 12.4 | 17.2 | 25.6 | 2,800 | 22.4 | 12.4 | 10.0 | 18.4 |
| 2,600 | 22.4 | 4.0 | 7.2 | 12.8 | 2,900 | 20.8 | 5.2 | 5.6 | 16.4 |

SOLUTION CONTAINED 240 PARTS PER MILLION $PO_4$.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3,100 | 39.2 | 4.0 | 8.4 | 24.8 | 3,500 | 16.8 | 5.2 | 5.6 | 18.4 |
| 3,300 | 76.0 | 4.8 | 8.0 | 36.8 | | | | | |

SOLUTION CONTAINED 240 PARTS PER MILLION $PO_4$.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3,700 | 28.0 | 10.0 | 12.0 | 14.0 | 3,900 | 24.0 | 4.0 | 6.4 | 13.6 |

*Summary of above table.*

| Soil No. | $PO_4$ added to 100 gm. soil. | $PO_4$ fixed by 100 gm. soil. | Per cent of $PO_4$ fixed. |
|---|---|---|---|
| | *Gram.* | *Gram.* | |
| 292 | 0.8308 | 0.7190 | 86.4 |
| 448 | .8308 | .8043 | 96.7 |
| 428 | .8308 | .7966 | 95.8 |
| 474 | .8308 | .7516 | 90.4 |

The series reported in the above table was started in glass tubes, 100 grams of soil being used in each instance, but it was found necessary to transfer the soils to funnels, as there was no percolation at all through soil No. 474, and it was extremely slow in Nos. 292, 448, and 428. The extracts all came through clear for about one month, after which they began coming through cloudy, and when the series was stopped the percolation was very slow even in the funnels.

Phosphoric acid being the constituent of phosphates which forms insoluble compounds with the bases always present in soils, such as iron, aluminum, titanium, lime, and magnesium, it is not very difficult to understand the retention of soluble phosphoric acid by soils. In the presence of sufficient calcium carbonate the application of soluble phosphoric acid will result in a "reversion" of the phosphate, i. e., the formation of the less soluble dicalcium phosphate which, however, is quite readily available, and hence there results a gain rather than a loss. But in case the soil is deficient in lime and contains an excess of iron and aluminum hydrates and silicates, similar to Hawaiian soils, an entirely different problem is encountered. In this case the phosphoric acid will be fixed by the iron and aluminum compounds, thus being rendered not only practically insoluble in water, but also in weak organic acid solvents. For such conditions various investigators recommend the application of lime preceding that of the superphosphate, the theory being that the lime will revert the phosphoric acid. This theory has been put in practice in the red clay soils of the Wahiawa district of Oahu, but has failed to produce any beneficial results. This is probably due to the excessive amounts of iron and aluminum hydrates in these soils.

As indicated in the preceding tables, there is considerable difference in the absorption of the potassium and calcium phosphates. Since they were not carried to the saturation point, we can only compare the rates of absorption, and here the fixation of calcium phosphate is strikingly faster. It will be seen that more phosphoric acid was fixed from calcium phosphate in two of the soils and practically the same in the other two, even though 1 liter more of the potassium phosphate solution was passed through. On the other hand, nearly the same weight of the salt has passed through, and the general property of absorption is similar. In both cases soil No. 292 fixed the least phosphoric acid, No. 474 next least, No. 428 next, and No. 448 the most. Both of the soils that fixed the least phosphoric acid contained a high percentage of phosphoric acid, a sufficiency of lime, and a high percentage of organic matter. It is probable that reversion takes place more quickly with the calcium salt, which accounts for the higher rate of fixation in this case. There appears to be little correlation between the rate of fixation and the mechanical composition of the soil in cases where the size of the particles is offset by the organic matter,

the highest and the lowest in fixing power being both sandy soils but differing in organic-matter content. The fact that the fixation of phosphoric acid from the calcium salt was not excessively greater than that from the potassium salt was probably due to the fixation being largely a result of the action of iron and aluminum compounds and only a partial reversion of the calcium salt. Crawley[1] found that upon irrigating Hawaiian soils immediately after application of water-soluble phosphate one-half of the phosphoric acid remained in the first inch of soil, nine-tenths in 3 inches, and practically all in 6 inches of the surface soil. These results indicate the absolute necessity of turning all applications of phosphate under by deep plowing in order to get the best results. Otherwise the rain is not able to wash it down to the roots, and consequently the dissemination of this fertilizer is incomplete.

At the point where these series were stopped the soils had apparently lost none of their fixing power. This fact lends very strong proof to the theory that the concentration of the soil solution with regard to phosphoric acid is not increased by the addition of this element in moderate quantities either as a soluble or insoluble salt; also, that while there are differences in the concentration of the solution in different soils, they are due to factors other than the solubility of the salt in water.

## ABSORPTION OF POTASH.

For the study of the absorption of potash a solution of potassium sulphate, containing about 200 parts per million of potassium (K) was used. The soils were the same as used in the phosphate series, and the method of percolation was through a column of 100 grams of the soil placed in glass tubes, as already described. At the outset the solution percolated quite rapidly, but after five days much more slowly in soils Nos. 292 and 428, and extremely slowly in soil No. 448. A precipitate, apparently of ferric hydrate, formed upon standing overnight in the extract from soil No. 292. After about one month the percolation from soil No. 448 (yellow clay soil) became so slow as to be several hundred cubic centimeters behind the rest of the series. However, strange to say, about one week following the date of above conditions, the percolation in soil No. 448 was faster than with the other soils, and when the experiments were stopped soil No. 474 was percolating the most slowly of all.

In order to get a clear conception regarding the absorption of potash, it is of some value to know the effect of leaching the soils with water upon the solubility of this element. The table following throws some light upon this.

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[1] Jour. Amer. Chem. Soc., 24 (1902), p. 1114.

*Potash removed from the soils by distilled water.*

[Expressed in parts per million of K in the percolate.]

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|
| 100 | 52 | 44 | 44 | 108 |
| 200 | .......... | 20 | 44 | 68 |
| 300 | 44 | 28 | 28 | 52 |
| 400 | 40 | 8 | 16 | 56 |
| 500 | 20 | 20 | 16 | 44 |

Thus it is shown that the general tendency of the soils was to yield a solution of fairly constant concentration. However, attention should be called to the fact that these figures do not represent parts per million in the soil, but simply in the solution obtained through percolation.

The following table shows the absorbing power of the soils for potash, using a solution containing 214 parts per million of potassium sulphate.

*Absorption of potash from a solution of $K_2SO_4$.*

[Expressed in parts per million of K in the percolate.]

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 60 | 52 | 48 | 100 | 1,800 | 140 | 164 | 184 | 172 |
| 200 | 52 | 92 | 56 | 80 | 1,900 | 132 | 148 | 188 | 160 |
| 300 | 40 | 80 | 40 | 76 | 2,000 | 128 | 164 | 192 | 176 |
| 400 | 64 | 100 | 52 | 84 | 2,100 | 120 | 188 | 180 | 168 |
| 500 | 76 | 140 | 124 | 104 | 2,200 | 100 | 172 | 184 | 156 |
| 600 | 56 | 148 | 152 | 88 | 2,300 | 148 | 172 | 188 | 180 |
| 700 | 60 | 160 | 156 | 96 | 2,400 | 132 | 200 | 172 | 156 |
| 800 | 72 | 164 | 188 | 84 | 2,500 | 116 | 200 | 180 | 168 |
| 900 | 76 | 188 | 192 | 88 | 2,700 | 136 | 200 | 200 | 188 |
| 1,000 | 76 | 168 | 192 | 76 | 2,900 | 152 | 204 | 216 | 168 |
| 1,100 | 64 | 168 | 212 | 72 | 3,100 | 152 | 224 | 224 | 184 |
| 1,200 | 84 | 196 | 192 | 84 | 3,300 | 184 | 212 | 232 | 204 |
| 1,300 | 136 | 208 | 200 | 84 | 3,500 | 152 | 220 | 216 | 208 |
| 1,400 | 96 | 204 | 204 | 104 | 3,700 | 160 | 204 | 224 | 212 |
| 1,500 | 120 | 172 | 200 | 116 | 3,900 | 148 | 216 | 204 | 168 |
| 1,600 | 128 | 160 | 204 | 140 | 4,100 | 164 | 228 | 200 | 200 |
| 1,700 | 124 | 160 | 196 | 160 | 4,300 | 164 | 220 | 228 | 212 |

*Summary of above table.*

| Soil No. | K added to 100 gm. soil. | K fixed by 100 gm. soil. | Per cent of K fixed. |
|---|---|---|---|
| | *Gram.* | *Gram.* | |
| 292 | 0.9030 | 0.4030 | 45 |
| 448 | .9030 | .1496 | 17 |
| 428 | .9030 | .2380 | 26 |
| 474 | .9030 | .2782 | 31 |

In order more easily to explain the absorption of potash by soils it is of considerable importance to know the effect of the addition of potash upon the solubility of the other bases commonly occurring in soils. For this reason several determinations were made to ascertain the concentration of lime and magnesia in the filtrate. The table following gives the results of these determinations.

*Effect of the potassium sulphate solution upon the solubility of lime and magnesia in the soils.*

[Expressed in parts per million in the percolate.]

| Percolates of 100 cc. each. | Lime. | | | | Magnesia. | | | |
|---|---|---|---|---|---|---|---|---|
| | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
| 100 | 104 | 44 | 40 | 514 | 102 | 24 | 34 | 82 |
| 300 | 56 | 28 | 10 | 146 | 70 | 34 | 28 | 46 |
| 500 | 66 | 22 | 24 | 150 | 94 | 32 | 26 | 40 |
| 700 | 50 | 20 | 24 | 158 | 72 | 32 | 18 | 38 |
| 900 | 68 | 36 | 24 | 164 | 68 | 26 | 22 | 38 |
| 2,700 | 36 | 24 | 12 | 70 | 32 | 24 | 22 | 24 |
| 3,300 | 26 | 14 | 8 | 48 | 54 | 26 | 34 | 34 |

The data presented in the preceding tables throw considerable light upon the retaining power which Hawaiian soils possess for potash. In the absorption of potash the salts undergo a decomposition, the result of which is a replacement of calcium or magnesium by potassium. The two former elements combine with the acid constituent of the potash salt and pass off in the drainage water. It has been found that potassium sulphate is more firmly fixed than the chlorid. In general the reaction taking place is a replacement of the calcium in the zeolitic silicates, but humus and the iron and aluminum hydrates also fix potash to a certain extent.

It may be seen from the above tables that the soil highest in lime and magnesia had the highest fixing power for potash, and the other three soils in proportion. This is in agreement with the findings of other investigators. Crawley[1] found that Hawaiian soils fixed potash quite firmly, but the fixation was not nearly so lasting as that of phosphoric acid. The results given herewith indicate this to be true and also the saturation point for potash to be far below that of phosphoric acid, even in the soils high in lime and magnesia. In the preceding table there are some very striking results showing the decrease in concentration of lime and magnesia in the filtrate, with decrease in amount of potash fixed by the soil. The fixation of this element in the soils highest in lime and magnesia is almost constant for the first liter of solution passing through the soil column. On the other hand, the fixing power of the other soils decreases more rapidly and they are more easily saturated, while the soil containing 8 per cent of magnesia had not reached a state of saturation at the close of the experiments.

## ABSORPTION OF NITROGEN.

### AMMONIUM SULPHATE.

This series was carried out in a manner similar to the previous one—namely, 100 grams of soil was placed in glass tubes, with percolation at the rate of 100 cubic centimeters per 24 hours. The percolate

[1] Jour. Amer. Chem. Soc., 25 (1903), p. 47.

remained clear through the series, except for a flocculent precipitate which appeared to be ferric hydrate, and which was deposited from soil No. 428.

The following table shows the amount of ammonia nitrogen removed from the original soils by distilled water:

*Ammonia nitrogen removed from the soils by distilled water.*

[Expressed in parts per million nitrogen in the percolate.]

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|
| 100 | 6.5 | 11.4 | 13.4 | 4.2 |
| 200 | 5.7 | 8.4 | 8.8 | 4.4 |
| 300 | 2.2 | 5.7 | 5.4 | 2.3 |
| 400 | 2.9 | 5.7 | 6.4 | 3.0 |
| 500 | .......... | 5.6 | 7.3 | 5.1 |

From these data it may be seen that these soils possess the same general tendency to produce a solution of constant nitrogen content.

In the following table may be observed the absorbing power of the soils for nitrogen in ammonium sulphate:

*Absorption of nitrogen from a solution of $(NH_4)_2 SO_4$.*

[Expressed in parts per million nitrogen in the percolate.]

SOLUTION USED CONTAINED 171 PARTS PER MILLION NITROGEN.

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 3.6 | 46.8 | 39.6 | 2.6 | 1,100 | 21.4 | 42.8 | 39.6 | 17.1 |
| 200 | 2.6 | 64.4 | 64.4 | 2.6 | 1,200 | 51.5 | 51.5 | 51.5 | 46.8 |
| 300 | 3.6 | 36.8 | 34.2 | 8.6 | 1,300 | 51.5 | 46.8 | 51.5 | 51.5 |
| 400 | 5.6 | 39.6 | 39.6 | 7.4 | 1,400 | 51.5 | 57.2 | 64.4 | 46.8 |
| 500 | 12.8 | 36.8 | 39.6 | 2.6 | 1,500 | 51.5 | 57.2 | 62.9 | 51.5 |
| 600 | 14.7 | 51.5 | 51.5 | 4.5 | 1,600 | 68.4 | 73.6 | 68.4 | 57.2 |
| 700 | 22.8 | 51.5 | 44.8 | 5.4 | 1,700 | 64.4 | 68.4 | 75.2 | 64.4 |
| 800 | 15.8 | 39.6 | 36.8 | 12.1 | 1,800 | 64.4 | 87.1 | 87.1 | 73.6 |
| 900 | 17.1 | 36.8 | 36.8 | 12.8 | 1,900 | 86.0 | 94.4 | 86 | 80.8 |
| 1,000 | 18.7 | 42.8 | 39.6 | 15.8 | | | | | |

SOLUTION USED CONTAINED 168 PARTS PER MILLION NITROGEN.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2,000 | 70.8 | 73.6 | 78.8 | 73.6 | 3,100 | 119 | 126 | 134 | 112 |
| 2,100 | 76.4 | 91.6 | 73.6 | 73.6 | 3,300 | 117.6 | 135.2 | 156.8 | 124.8 |
| 2,200 | 123.6 | 128 | 117.9 | 96.6 | 3,500 | 186 | 163 | 138 | 148 |
| 2,300 | 105.2 | 93.3 | 117.1 | 73.2 | 3,700 | 156.5 | 148.9 | 115.6 | 139.8 |
| 2,400 | 114.1 | 128.8 | 128.8 | 128.8 | 3,900 | 152.4 | 149.9 | 88.8 | 137.6 |
| 2,500 | 121.2 | 121.2 | 128.8 | 121.2 | 4,100 | 152 | 152 | 120.8 | 141.6 |
| 2,700 | 117 | 156.6 | 174.2 | 143 | 4,300 | 147.2 | 137.6 | 120 | 120 |
| 2,900 | 156.4 | 158.4 | 167.8 | 140.7 | 4,500 | 164.8 | 171.2 | 164.8 | 164.8 |

*Summary of above table.*

| Soil No. | Nitrogen added to 100 gm. soil. | Nitrogen fixed by 100 gm. soil. | Per cent of nitrogen fixed. |
|---|---|---|---|
| | *Gram.* | *Gram.* | |
| 292 | 0.6811 | 0.2782 | 41 |
| 448 | .6811 | .2290 | 34 |
| 428 | .6811 | .2753 | 40 |
| 474 | .6811 | .3015 | 44 |

The nature of the reaction accompanying the absorption of ammonium compounds is very similar to that of potash salts, namely, the replacing of calcium in humus, double silicates, and in some cases calcium carbonate. Hence the application of ammonium salts as fertilizer tends to deplete the soil of its basic constituents.

It may be seen from a comparison of the preceding tables that the fixation of nitrogen is far in excess of that of potash in every instance except soil No. 292, which is the highest in magnesia content. The fixing power of the four soils in the series agrees more closely than in the potash series, but in each instance the clay soil fixed the least. Attention is called to soils Nos. 428, 448, and 474, which absorb much more nitrogen than potash. In case of two of the soils (428 and 474) this may be accounted for by the high content of organic matter. In the last two, fractions of percolate nitrates and nitrites were determined and both were found to be present in one case to the extent of 14.4 parts per million N as $NO_3$ and 3.1 parts per million N as $NO_2$. This indicates the rate at which nitrification was going on at the close of the experiments.

As in the potash series, the highly basic soils fixed much more nitrogen at the beginning of the experiments and a much larger total amount than the less basic. On the other hand, the decrease in fixing power was much slower and more gradual in the other soils.

## SODIUM NITRATE.

Of the salts commonly used as fertilizing materials all are strongly fixed by the soil except nitrates. However, nature has made a wise provision for retaining nitrogen in an insoluble form, which becomes slowly available for growing plants. Determinations of the amount of nitrate nitrogen removed from the original soils gave the following results:

*Nitrate nitrogen removed from the soils by distilled water.*

[Expressed in parts per million nitrogen in the percolate.]

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|
| 100 | 4.2 | 8.6 | 5.9 | 106 |
| 200 | 2.4 | .0 | .0 | 2 |
| 300 | .0 | .0 | .0 | .4 |

These data indicate a condition found to be true in all soils, namely, the readiness with which nitrates are leached from the soil by rains. Soil No. 474 is a very porous, floury soil, containing a high percentage of organic matter, and under the existing climatic conditions would be expected to have a high nitrate content.

The following table shows the absorbing power of these soils for nitrate nitrogen, using a solution of sodium nitrate which contained 250 parts per million of nitrogen:

*Absorption of nitrogen from a solution of $NaNO_3$.*

[Expressed in parts per million of nitrogen in the percolate.]

| Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. | Percolates of 100 cc. each. | Soil No. 292. | Soil No. 448. | Soil No. 428. | Soil No. 474. |
|---|---|---|---|---|---|---|---|---|---|
| 100.......... | 147 | 157 | 142 | 290 | 1,000.......... | 240 | 225 | 230 | 195 |
| 200.......... | 184 | 162 | 180 | 170 | 1,100.......... | 240 | 230 | 230 | 185 |
| 300.......... | 215 | 190 | 180 | 200 | 1,200.......... | 230 | 235 | 235 | 215 |
| 400.......... | 245 | 240 | 205 | 235 | 1,300.......... | 240 | 235 | 240 | 215 |
| 500.......... | 240 | 245 | 225 | 235 | 1,400.......... | 245 | 240 | 240 | 215 |
| 600.......... | 225 | 220 | 220 | 200 | 1,500.......... | 250 | 245 | 250 | 220 |
| 700.......... | 205 | 205 | 215 | 195 | 1,600.......... | 250 | 250 | 250 | 225 |
| 800.......... | 230 | 240 | 215 | 220 | 1,700.......... | 250 | 250 | 250 | .......... |
| 900.......... | 230 | 225 | 225 | 175 | 1,800.......... | 250 | 250 | .......... | .......... |

*Summary of above table.*

| Soil No. | Nitrogen added to 100 gm. soil. | Nitrogen fixed by 100 gm. soil. | Per cent of nitrogen fixed. |
|---|---|---|---|
| | *Gram.* | *Gram.* | |
| 292.......... | 0.4500 | 0.0384 | 8.5 |
| 448.......... | .4500 | .0456 | 10 |
| 428.......... | .4250 | .0518 | 12 |
| 474.......... | .4000 | .0610 | 15 |

The above table presents some very interesting data. It is quite generally conceded that soils have no fixing power for nitrates and for this reason it is difficult to explain the action of soil No. 474 toward this salt. The percolation was very slow in this instance and the rate decreased to such an extent that the series had to be stopped after 1,600 cubic centimeters had passed through, as the solution would no longer filter through the column. This condition exists in spite of the fact that the soil contained only an extremely small percentage of clay. Soil No. 428 acted somewhat similarly, but percolation did not stop completely as in the case of No. 474. This condition is undoubtedly brought about by the action of sodium nitrate upon the organic matter, as both of these soils were high in this constituent. Soil No. 474 was apparently still fixing nitrogen at the close of the experiment, as in no case except with the first 100 cubic centimeters did the percolate reach a concentration of 250 parts per million. These figures indicate that while soils are unable to retain nitrates against the action of nitrate-free water, they are able to retain limited amounts against the action of water with a high nitrate content. It is possible that considerable denitrification took place in soil No. 474. The sluggish movement of the solution through this soil indicates the existence of just the conditions which are conducive to denitrification. The same is true of No. 428.

Denitrification refers, of course, to any transformation which nitrates may undergo, such as its conversion into nitrate, ammonia, free nitrogen, or protein.

## ABSORPTION OF FERTILIZER SALTS BY FRESH AND AIR-DRIED SOILS.

The type of soil occurring in greatest abundance on the islands is a highly ferruginous red clay (No. 517). For this reason it was decided to make a series of percolations using both soil and subsoil of this type in the fresh and air-dry condition, using sodium nitrate, ammonium sulphate, potassium phosphate, and calcium phosphate.

The fresh soil contained 19.7 per cent moisture; the fresh subsoil, 24.4 per cent moisture.

The method employed was essentially the same as that used in the previous series except that it was found to be necessary to use only 50 grams of soil with the phosphates in order to effect a passage of the solution through the soil column. Also the concentration of the solution was increased in an attempt to saturate the soil with phosphates. Determinations were made of the solubility in distilled water of the phosphate in the saturated soil, and it was found to be negligible. On passing distilled water through a column of 50 grams of soil and determining the percentage of phosphoric acid in each 100 cubic centimeters passing through, only a faint trace was detected.

### ABSORPTION OF PHOSPHORIC ACID.

The following table shows the absorbing power of the red clay soil for phosphoric acid when applied as monopotassium phosphate:

*Absorption of phosphoric acid from a solution of $KH_2PO_4$.*

[Expressed in parts per million of $PO_4$ in the percolate.]

$PO_4$ IN SOLUTION, 800 PARTS PER MILLION.

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 44 | 72 | Trace. | Trace. | 400 | 180 | 260 | 24 | 32 |
| 200 | 38 | 128 | 21 | 27 | 500 | 220 | 340 | ........ | ........ |
| 300 | 124 | 165 | 22 | 29 | 600 | 290 | 340 | ........ | ........ |
| $PO_4$ IN SOLUTION, 1,400 PARTS PER MILLION. | | | | | | | | | |
| 500 | ........ | ........ | 150 | 290 | 1,300 | 950 | 850 | ........ | ........ |
| 600 | ........ | ........ | 325 | 325 | 1,400 | 900 | 825 | ........ | ........ |
| 700 | 410 | 460 | 350 | 360 | 1,500 | 750 | 750 | ........ | ........ |
| 800 | 390 | 460 | 560 | 665 | 1,600 | 750 | 750 | ........ | ........ |
| 900 | 400 | 500 | 675 | 675 | 1,700 | 725 | 600 | ........ | ........ |
| 1,000 | 430 | 500 | 825 | 825 | 1,800 | 875 | 850 | ........ | ........ |
| 1,100 | 530 | 400 | ........ | ........ | 1,900 | 675 | 675 | ........ | ........ |
| 1,200 | 620 | 560 | ........ | ........ | 2,000 | 875 | 825 | ........ | ........ |
| $PO_4$ IN SOLUTION, 1,025 PARTS PER MILLION. | | | | | | | | | |
| 1,500 | ........ | ........ | 700 | 700 | 2,800 | ........ | ........ | 950 | 950 |
| 1,750 | ........ | ........ | 675 | 675 | 3,250 | 600 | 600 | ........ | ........ |
| 2,250 | ........ | ........ | 600 | 600 | 3,300 | ........ | ........ | 1,025 | 1,025 |
| 2,500 | 750 | 675 | ........ | ........ | 3,800 | 950 | 950 | ........ | ........ |
| 2,725 | 675 | 675 | ........ | ........ | 4,300 | 1,025 | 1,025 | ........ | ........ |

*Summary of preceding table.*

| Soil. | $PO_4$ added to 100 gm. soil. | $PO_4$ fixed by 100 gm. soil. | Per cent of $PO_4$ fixed. |
|---|---|---|---|
| | *Grams.* | *Grams.* | |
| Fresh soil | 9.5950 | 3.8062 | 39.6 |
| Fresh subsoil | 9.5950 | 3.8544 | 40.2 |
| Air-dry soil | 6.8350 | 2.7372 | 40.1 |
| Air-dry subsoil | 6.8350 | 2.6820 | 39.3 |

The absorption of phosphoric acid from monocalcium phosphate was as follows:

*Absorption of phosphoric acid from a solution of $CaH_4 (PO_4)_2$.*

[Expressed in parts per million of $PO_4$ in the percolate.]

SOLUTION CONTAINED 1,300 PARTS PER MILLION $PO_4$.

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 210 | 210 | 203 | 203 | 400 | 700 | 650 | 700 | 703 |
| 200 | 470 | 490 | 750 | 700 | 500 | 1,012 | 1,012 | ...... | ...... |
| 300 | 615 | 585 | 625 | 800 | 600 | 925 | 1,200 | ...... | ...... |

SOLUTION CONTAINED 1,700 PARTS PER MILLION $PO_4$.

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 500 | ...... | ...... | 775 | 775 | 1,300 | 1,100 | 1,100 | ...... | ...... |
| 600 | ...... | ...... | 850 | 850 | 1,400 | 1,200 | 1,150 | ...... | ...... |
| 700 | 1,300 | 1,275 | 1,250 | 1,100 | 1,500 | 1,350 | 1,400 | ...... | ...... |
| 800 | 825 | 950 | 1,000 | 1,000 | 1,600 | 1,350 | 1,250 | ...... | ...... |
| 900 | 900 | 950 | 1,100 | 1,250 | 1,700 | 1,350 | 1,250 | ...... | ...... |
| 1,000 | 1,100 | 1,100 | 1,025 | 1,000 | 1,800 | 1,250 | 1,325 | ...... | ...... |
| 1,100 | 1,100 | 1,100 | 850 | 975 | 1,900 | 925 | 925 | ...... | ...... |
| 1,200 | 950 | 950 | 1,300 | 1,275 | | | | | |

SOLUTION CONTAINED 2,812 PARTS PER MILLION $PO_4$.

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 1,700 | ...... | ...... | 1,300 | 1,250 | 2,750 | 1,250 | ...... | ...... | ...... |
| 1,925 | ...... | ...... | ...... | 1,250 | 3,000 | ...... | ...... | 2,812 | 2,812 |
| 1,950 | ...... | ...... | 1,300 | ...... | 3,250 | 1,600 | 1,550 | ...... | ...... |
| 2,000 | 1,350 | 1,350 | ...... | ...... | 3,500 | ...... | ...... | 2,812 | 2,812 |
| 2,450 | ...... | ...... | 1,600 | ...... | 3,800 | 2,812 | 2,812 | ...... | ...... |
| 2,500 | 1,450 | 1,350 | ...... | 1,600 | 4,300 | 2,812 | 2,812 | ...... | ...... |
| 2,725 | ...... | 1,400 | ...... | ...... | | | | | |

*Summary of above table.*

| Soil. | $PO_4$ added to 100 gm. soil. | $PO_4$ fixed by 100 gm. soil. | Per cent of $PO_4$ fixed. |
|---|---|---|---|
| | *Grams.* | *Grams.* | |
| Fresh soil | 8.3328 | 5.9110 | 70.9 |
| Fresh subsoil | 8.3328 | 5.9880 | 71.8 |
| Air-dry soil | 6.9416 | 5.5232 | 79.6 |
| Air-dry subsoil | 6.9416 | 5.4732 | 78.8 |

The results in the above tables can be compared with those of the previous series only relatively, due to the fact that the solution in this case was so much more concentrated. They indicate the practical impossibility of saturating Hawaiian soils with phosphoric acid or adding an excess in a practical way. It will be noted that this type of soil is able to absorb nearly 4 per cent of its weight of phosphoric acid ($PO_4$) in the fresh soil and nearly 3 per cent in the air-dry soil from the potassium salt; also, that from the calcium salt the soil absorbed nearly 6 per cent of its own weight of phosphoric acid in the fresh soil and 5.5 per cent in the air-dry soil. It is difficult to explain the higher absorptive power of the fresh soil over the air dry, but it is probably due to the physical properties, and is related to the soil films.

This soil is composed of very fine particles, exposing relatively enormous surface to the action of the soil solution or any added salt solution. In the fresh soils of this type these particles are in a high state of deflocculation and the effect of drying in the air tends to flocculate them to a great extent, thereby reducing the area of the exposed surface. Drying would also tend to modify the film surrounding each particle. Even with only 50 grams of soil it was found impossible, due to the strong deflocculating action of the phosphate salts, to make the percolations in tubes, but funnels had to be used. The samples previously dried in the air percolated more slowly than the fresh soils. This is probably due to the fact that the soil swelled more in the tube after the addition of the solution, thus packing more closely and closing up the pore spaces.

There was apparently very little difference between the absorbing power of the soil and subsoil, but considerable variation between the fresh and air-dry soils. The rate of fixation in the early part of the experiment was considerably faster in the latter than in the former, and hence the air-dry soils were more quickly saturated by the salts. Another interesting fact is the difference in the absorptive power of this type of soil for phosphoric acid in the two forms. The data are sufficient to justify the statement that this difference is due to the reversion of the calcium salt, although due also in great part to the state of the iron and aluminum compounds which exist in this type of soil. The absorption from the potash salt was more complete at the first application, but thereafter decreased quite rapidly and regularly. It should also be noted that at the outset the air-dry soil absorbed the potash salt more completely than the fresh soil. This is thought to be due to the partial elimination of the film surrounding the soil particles, thus allowing the solution to penetrate more thoroughly.

## ABSORPTION OF POTASH.

The strength of solution used in the potash series was the same as in the first series. One hundred-gram portions of soil were used. The results of extraction of the original soils are given in the following tables:

*Removal of potash from soil by distilled water.*

[Expressed in parts per million of K in the percolate.]

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 40 | 32 | 64 | 32 | 400 | 52 | 84 | 27 | 23 |
| 200 | 17.4 | 14.8 | 52 | 36 | 500 | 68 | 16 | ........ | ........ |
| 300 | 56 | 32 | 48 | 32 | 600 | 32 | ........ | ........ | ........ |

The results of determinations of the absorption of potash from potassium sulphate are given in the following table:

*Absorption of potash from a solution containing 204 parts per million K from $K_2SO_4$.*

[Expressed in parts per million in the percolate.]

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 64 | 52 | 52 | 68 | 1,000 | 172 | 176 | 180 | 176 |
| 200 | 68 | 44 | 80 | 24 | 1,100 | 152 | 152 | 180 | 192 |
| 300 | 212 | 136 | 104 | 60 | 1,200 | ........ | ........ | 196 | 184 |
| 400 | 216 | 160 | 180 | 120 | 1,300 | ........ | ........ | 192 | 200 |
| 500 | 164 | 168 | 180 | 120 | 1,400 | 200 | 200 | 172 | 180 |
| 600 | 172 | 180 | 180 | 120 | 1,500 | 200 | 192 | 196 | 176 |
| 700 | 192 | 180 | 172 | 140 | 1,600 | 216 | 212 | 204 | 188 |
| 800 | 180 | 180 | 184 | 180 | 1,700 | 208 | 204 | 188 | 192 |
| 900 | 184 | 196 | 192 | 180 | 1,800 | ........ | ........ | 212 | 200 |

*Summary of above table.*

| Soil. | K added to 100 gm. soil. | K fixed by 100 gm. soil. | Per cent of K fixed. |
|---|---|---|---|
| | *Grams.* | *Grams.* | |
| Fresh soil | 0.3468 | 0.0468 | 13.5 |
| Fresh subsoil | .3468 | .0636 | 18.3 |
| Air-dry soil | .3672 | .0528 | 14.4 |
| Air-dry subsoil | .3672 | .0972 | 26.5 |

The effect of the potassium sulphate solution on the solubility of lime and magnesia is shown in the following table:

*Effect of potassium sulphate solution upon the solubility of lime and magnesia.*

[Expressed in parts per million in the percolate.]

| Percolates of 100 cc. each. | Lime (CaO). | | | | Magnesia (MgO). | | | |
|---|---|---|---|---|---|---|---|---|
| | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
| 100 | 60 | 38 | 62 | 50 | 34 | 28 | 34 | 30 |
| 300 | 50 | 64 | 38 | 54 | 56 | 56 | 18 | 20 |
| 600 | 44 | 34 | 62 | 52 | 20 | 20 | 20 | 20 |
| 1,700 | 24 | 16 | 20 | 24 | 18 | 12 | 14 | 12 |

These tables indicate that the potash in this type of soil is quite soluble. The fixing power of this soil is far below that of the four soils used in the previous series; that is, the red clay soil of the islands is more easily saturated with potash than the other types. This is partly due to the low lime and magnesia content of this soil. The two series illustrate quite well the effect of these bases upon the fixation of potash. The figures in the table on page 19 indicate the subsoil to have the power of fixing more potash than the soil, and that drying in the air tends to increase this power.

## ABSORPTION OF NITROGEN.

### AMMONIUM SULPHATE.

This series was carried through similarly to the previous ammonium sulphate series. A table showing the solubility in distilled water of the ammonia nitrogen in the original soil is given herewith:

*Ammonia nitrogen removed from the soil by distilled water.*

[Expressed in parts per million nitrogen in the percolate.]

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|
| 100 | 5.1 | Trace. | 7.47 | 5.04 |
| 200 | Trace. | Trace. | 11.16 | 6.1 |
| 300 | Trace. | Trace | Trace. | 7.2 |

This type of soil is shown to contain only small amounts of ammonia nitrogen soluble in water, the amounts being slightly lower than those found in the previous series.

The following table shows the absorbing power of this soil for ammonium nitrogen:

*Absorption of nitrogen from a solution of* $(NH_4)_2SO_4$.

[Expressed in parts per million in the percolate.]

SOLUTION CONTAINED 246 PARTS PER MILLION NITROGEN FROM $(NH_4)_2SO_4$.

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 26.5 | 17.8 | 12.5 | 25.2 | 700 | 151.3 | 157.1 | 188 | 172 |
| 200 | 65.2 | 54.9 | 113.2 | 111 | 800 | 192.9 | 178.6 | 180 | 172 |
| 300 | 71.6 | 66.6 | 178.2 | 145.6 | 900 | 178.6 | 152.3 | 206 | 184 |
| 400 | 185 | 143 | 162.3 | 149.6 | 1,000 | 239 | 204 | 188 | 184 |
| 500 | 181.3 | 183.3 | 165.1 | 168.9 | 1,100 | 224 | 242 | 224 | 214 |
| 600 | 211.5 | 167.4 | 172 | 160 | | | | | |

SOLUTION CONTAINED 204 PARTS PER MILLION NITROGEN FROM $(NH_4)_2SO_4$.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1,200 | 181.4 | 182.6 | 224 | 214 | 1,400 | 212 | 212 | 206 | 206 |
| 1,300 | 211.6 | 200 | 206 | 206 | | | | | |

*Summary of preceding table.*

| Soil. | Nitrogen added to 100 gm. soil. | Nitrogen fixed by 100 gm. soil. | Per cent of nitrogen fixed. |
|---|---|---|---|
| | *Gram.* | *Gram.* | |
| Fresh soil | 0.3318 | 0.1000 | 30.1 |
| Fresh subsoil | .3318 | .1164 | 35 |
| Air-dry soil | .2706 | .0916 | 33.9 |
| Air-dry subsoil | .2706 | .1019 | 37.6 |

Since ammonium salts are retained by the soil in most respects by the same reactions which govern the absorption of potash, we would expect the red clay soil to have the low absorptive power shown in the above table, which is less than one-half that of the soils used in the previous series. The subsoil showed a slightly higher fixing power than the soil, while the effect of drying in the air was to reduce the fixing power. This latter finding is just the reverse of that obtained in case of potash.

## SODIUM NITRATE.

The absorbing power of this soil for sodium nitrate is very much lower than that of the other types, as may be seen from the following tables:

*Removal of nitrate nitrogen from soil by distilled water.*

[Expressed in parts per million of nitrogen in the percolate.]

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|
| 100 | 19.2 | 8.8 | 12.8 | 7.2 |
| 200 | ....... | ....... | ....... | ....... |

*Absorption of nitrogen from a solution of 250 parts per million nitrogen from $NaNO_3$.*

[Expressed in parts per million of nitrogen in the filtrate.]

| Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. | Percolates of 100 cc. each. | Fresh soil. | Fresh subsoil. | Air-dry soil. | Air-dry subsoil. |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 187.5 | 180.0 | 215.0 | 215.0 | 300 | 250.0 | 250.0 | 250.0 | 250.0 |
| 200 | 250 | 255 | 240 | 240 | 400 | 250 | 250 | 250 | 250 |

*Summary of above table.*

| Soil. | Nitrogen added to 100 gm. soil. | Nitrogen fixed by 100 gm. soil. | Per cent of nitrogen fixed. |
|---|---|---|---|
| | *Gram.* | *Gram.* | |
| Fresh soil | 0.1000 | 0.0062 | 6.2 |
| Fresh subsoil | .1000 | .0065 | 6.5 |
| Air-dry soil | .1000 | .0045 | 4.5 |
| Air-dry subsoil | .1000 | .0045 | 4.5 |

The above results show the low fixing power of this type of soil for nitrates. This fact strongly indicates the rôle of organic matter in the absorption of this salt. The organic matter content of the previous series of soils was much higher than that of the red clay. There was apparently no difference between the fixing power of the soil and the subsoil, but it was stronger in the fresh than in the air-dried samples.

## ABSORPTION OF FERTILIZER SALTS WHEN APPLIED IN MIXTURES, AND THE EFFECT OF HEAT AND ANTISEPTICS.

A third series of experiments was made with the idea in mind of applying a solution containing a mixture of fertilizer salts and at the same time determining the effect of heat and volatile antiseptics upon the absorbing power. The soils chosen for this series were No. 428, a highly organic soil used in the first series, and No. 517, the red clay soil used in the second series. Three fertilizer mixtures were used and applied to the soil in series of three, namely, untreated, heated (230° C. in air bath), and partially sterilized (5 cubic centimeters chloroform to 100 grams soil kept in a closed fruit jar 48 hours, then spread out in the air 24 hours before placing in the glass tubes). The mixtures were as follows: (1) ammonium sulphate, potassium phosphate, and potassium sulphate; (2) ammonium sulphate, calcium phosphate, and potassium sulphate; and (3) sodium nitrate, calcium phosphate, and potassium sulphate. The solutions were allowed to percolate through the soil at the rate of 100 cubic centimeters in 24 hours, and the percolates were analyzed.

### ABSORPTION OF PHOSPHORIC ACID.

The table following shows the fixing power of these soils for phosphoric acid when applied in mixtures.

*Absorption of calcium and potassium phosphate in solutions of fertilizer mixtures.*

[Expressed in parts per million of $PO_4$ in the percolate.]

| Percolates of 100 cc. each. | Soil No. 517. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | | Sodium nitrate, calcium phosphate, and potassium sulphate. | | |
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 100 | Trace. | 46 | 26 | 26 | 38 | 44 | 224 | 50 | 280 |
| 200 | 86 | 34 | 34 | 50 | 120 | 380 | 360 | 56 | 400 |
| 300 | 140 | 22 | 100 | 392 | 512 | 448 | 232 | 328 | 256 |
| 500 | 200 | 70 | 240 | 550 | 650 | 700 | 600 | 550 | 750 |
| 700 | 480 | 360 | 460 | 1,700 | 1,550 | 1,750 | 1,050 | 1,050 | 1,050 |
| 900 | 168 | Trace. | 200 | 1,600 | 1,700 | 1,650 | 1,400 | 1,350 | 1,350 |
| 1,100 | 480 | 420 | 540 | 1,750 | 1,750 | 2,000 | 1,400 | 1,050 | 1,450 |
| 1,300 | 480 | 460 | 540 | 1,600 | 1,650 | 1,850 | 1,350 | 1,100 | 1,400 |
| 1,500 | 540 | 540 | 680 | 1,700 | 1,750 | 1,750 | 1,250 | 1,500 | 1,550 |
| 1,700 | 480 | 500 | 500 | 1,500 | 1,800 | 1,700 | 1,500 | 1,150 | 1,150 |
| 1,900 | 580 | 640 | 640 | 1,950 | 1,950 | 2,000 | ........ | ........ | ........ |
| 2,100 | 560 | 560 | 660 | 1,950 | 2,000 | 2,000 | ........ | ........ | ........ |

SUMMARY.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $PO_4$ added to 100 grams soil, grams. | 1.5750 | 1.5750 | 1.5750 | 4.3050 | 4.3050 | 4.3050 | 2.8050 | 2.8050 | 2.8050 |
| $PO_4$ fixed by 100 grams soil, grams. | .7588 | .8548 | .6670 | 1.3982 | 1.2780 | 1.0678 | 1.6134 | 1.2116 | 1.5014 |
| Per cent of $PO_4$ fixed | 48.2 | 54.3 | 42.3 | 32.5 | 29.7 | 24.7 | 57.3 | 43.2 | 53.5 |

| Percolates of 100 cc. each. | Soil No. 428. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | | Sodium nitrate, calcium phosphate, and potassium sulphate. | | |
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 100 | Trace. | 20 | Trace. | 19 | 15 | Trace. | 21 | 30 | 26 |
| 200 | 16 | 13 | 20 | 16 | 15 | 15 | 15 | 14 | 20 |
| 300 | 16 | 13 | 20 | 16 | 15 | 15 | 15 | 14 | 20 |
| 500 | 12 | 12 | 12 | 11 | 10 | 11 | 11 | 10 | 12 |
| 700 | 33 | 16 | 15 | 16 | 8 | 15 | 20 | 28 | 28 |
| 900 | 19 | 9 | 14 | 21 | 36 | 6 | 19 | 9 | 8 |
| 1,100 | 19 | 90 | 19 | 6 | 6 | 9 | 8 | 5 | 8 |
| 1,300 | 18 | 236 | 20 | 8 | 19 | 8 | 8 | 6 | 10 |
| 1,500 | 7 | 236 | 6 | 6 | 15 | 8 | 7 | 5 | 8 |
| 1,700 | 11 | 264 | 21 | 9 | 33 | 12 | ........ | ........ | ........ |
| 1,900 | 22 | 240 | 21 | 17 | 36 | 18 | ........ | ........ | ........ |
| 2,100 | 31 | 320 | 16 | 13 | 70 | 14 | ........ | ........ | ........ |

SUMMARY.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $PO_4$ added to 100 grams soil, grams. | 1.4700 | 1.4700 | 1.4700 | 0.8265 | 0.8265 | 0.8265 | 0.6375 | 0.6375 | 0.6375 |
| $PO_4$ fixed by 100 grams soil, grams. | 1.4296 | 1.1104 | 1.4298 | .7995 | .7754 | .8033 | .61.78 | .6191 | .6161 |
| Per cent of $PO_4$ fixed | 97.1 | 75.5 | 97.1 | 96.8 | 93.9 | 97.3 | 96.9 | 97.3 | 96.7 |

The solution used in the first series of three, columns 1, 2, and 3, contained 750 parts per million $PO_4$ from potassium phosphate; 4, 5, and 6, 2,050 parts per million $PO_4$ from calcium phosphate; 7, 8, and 9, 1,650 parts per million $PO_4$ from calcium phosphate; 10, 11, and 12, 700 parts per million $PO_4$ from potassium phosphate; 13, 14, and 15, 435 parts per million $PO_4$ from calcium phosphate; 16, 17, and 18, 425 parts per million $PO_4$ from calcium phosphate. The solution used with soil No. 428 was made up to a much weaker strength for the reason that it would be more comparable with the results obtained on this soil given in the first series.

The absorbing power of the red clay soil was appreciably less for phosphates in mixtures, but that of the highly organic soil is very much the same, regardless of method of application. The effect of heat or antiseptics was not striking, but in most instances caused a decrease in the fixing power. In one instance, namely, with the highly organic soil, the heat caused a decided decrease in fixing power.

## ABSORPTION OF POTASH.

The results obtained with the application of potash in mixtures are shown in the following table:

*Absorption of potash from a solution of fertilizer mixtures.*

[Expressed in parts per million K in the percolate.]

| Percolates 100 cc. each. | Soil No. 517. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | | Sodium nitrate, calcium phosphate, and potassium sulphate. | | |
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 100 | 196 | 180 | 268 | 172 | 120 | 156 | 108 | 112 | 144 |
| 200 | 348 | 316 | 300 | 152 | 132 | 88 | 104 | 132 | 108 |
| 300 | 440 | 440 | 376 | 44 | 80 | 72 | 176 | 104 | 68 |
| 500 | 484 | 460 | 480 | 88 | 84 | 64 | 84 | 120 | 108 |
| 700 | 544 | 508 | 552 | 188 | 224 | 228 | 216 | 232 | 140 |
| 900 | 540 | 580 | 524 | 164 | 260 | 276 | 204 | 228 | 208 |
| 1,100 | 540 | 584 | 572 | 124 | 216 | 200 | 180 | 188 | 232 |
| 1,300 | 564 | 576 | 588 | 184 | 288 | 204 | 256 | 180 | 132 |
| 1,500 | 544 | 560 | 504 | 156 | 224 | 176 | 228 | 236 | 172 |
| 1,700 | 544 | 576 | 528 | 152 | 244 | 140 | 156 | 360 | 280 |
| 1,900 | 488 | 564 | 544 | 196 | 188 | 216 | 284 | ........ | 288 |
| 2,100 | 428 | 528 | 496 | 164 | 192 | 184 | 212 | 368 | 248 |

SUMMARY.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| K added to 100 grams soil........grams.. | 1.0038 | 1.0038 | 1.0038 | 0.3570 | 0.3570 | 0.3570 | 0.4536 | 0.4536 | 0.4536 |
| K fixed by 100 grams soil........grams.. | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| Per cent of K fixed. | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |

*Absorption of potash from a solution of fertilizer mixtures*—Continued.

| Percolates of 100 cc. each. | Soil No. 428. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | | Sodium nitrate, calcium phosphate, and potassium sulphate. | | |
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 100 | 96 | 432 | 112 | 96 | 272 | 118 | 148 | 268 | 104 |
| 200 | 168 | 432 | 192 | 104 | 192 | 104 | 76 | 192 | 72 |
| 300 | 300 | 520 | 292 | 144 | 188 | 140 | 112 | 224 | 112 |
| 500 | 360 | 516 | 400 | 212 | 220 | 192 | 192 | 240 | 180 |
| 700 | 416 | 552 | 428 | 216 | 268 | 248 | 204 | 228 | 188 |
| 900 | 420 | 572 | 432 | 184 | 224 | 196 | 192 | 220 | 216 |
| 1,100 | 368 | 608 | 412 | 224 | 224 | 216 | 188 | 228 | 188 |
| 1,300 | 416 | 620 | 424 | 212 | 180 | 180 | 188 | 200 | 192 |
| 1,500 | 416 | 580 | 408 | 232 | 200 | 192 | 240 | 292 | 252 |
| 1,700 | 456 | 620 | 460 | 212 | 220 | 224 | ........ | ........ | ........ |
| 1,900 | 424 | 600 | 448 | 228 | 212 | 200 | ........ | ........ | ........ |
| 2,100 | 432 | 524 | 448 | 224 | 236 | 236 | ........ | ........ | ........ |

SUMMARY.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| K added to 100 grams soil.......grams.. | 1.2264 | 1.2264 | 1.2264 | 0.3822 | 0.3822 | 0.3822 | 0.3090 | 0.3090 | 0.3090 |
| K fixed by 100 grams soil.......grams.. | .9468 | ........ | 1.0224 | ........ | ........ | ........ | ........ | ........ | ........ |
| Per cent of K fixed. | 77.6 | ........ | 83.6 | ........ | ........ | ........ | ........ | ........ | ........ |

The above table presents some striking results, and indicates that Hawaiian soils possess a very low fixing power for potash when applied with phosphates, especially calcium phosphate. In every instance, except two, the amount of potash found in the filtrate was greater than the weight added to the soil. This is undoubtedly due partly to a replacement of the potash by lime. The effect of heat in case of the highly organic soil was to considerably reduce the fixing power, but chloroform reduced it only slightly. With the red clay soil there was very little variation, due to sterilization either with heat or antiseptics. This was contrary to the results obtained when potash was used alone. Drying in the air increased the fixing power.

The solutions used on samples reported in columns 1, 2, and 3 contained 478 parts per million K from $K_2SO_4$; 4, 5, and 6, 170 parts per million; 7, 8, and 9, 216 parts per million; 10, 11, and 12, 584 parts per million; 13, 14, and 15, 182 parts per million; 16, 17, and 18, 206 parts per million.

## ABSORPTION OF NITROGEN.

### AMMONIUM SULPHATE.

The following table shows the results obtained by the application of ammonium sulphate in mixtures:

*Absorption of nitrogen from a solution of ammonium sulphate in a mixed fertilizer.*

[Expressed in parts per million nitrogen in the percolate.]

| Percolates of 100 cc. each. | Soil No. 517. | | | | | |
|---|---|---|---|---|---|---|
| | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | |
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 100 | 81.5 | 188.4 | 88.9 | 64.9 | 133.9 | 91.3 |
| 200 | 128.8 | 148.6 | ........ | 125.4 | 167.2 | 168.7 |
| 30 | 99 | 138 | 111 | 135 | 144 | 114 |
| 500 | 130 | 133 | 128 | 148 | 143 | 153 |
| 700 | 131 | 130 | 129 | 168 | 128 | 136 |
| 900 | 137 | 174 | 136 | 156 | 159 | 156 |
| 1,100 | 149 | 141 | 151 | 153 | 151 | 164 |
| 1,300 | 178 | 166 | 178 | 175 | 170 | 163 |
| 1,500 | 178 | 178 | 178 | 159 | 159 | 172 |
| 1,700 | 172 | 172 | 172 | 172 | 172 | 172 |
| 1,900 | ........ | ........ | ........ | ........ | ........ | ........ |

SUMMARY.

| | | | | | | |
|---|---|---|---|---|---|---|
| Nitrogen added to 100 grams soil..........gram.. | 0.1892 | 0.1892 | 0.1892 | 0.1892 | 0.1892 | 0.1892 |
| Nitrogen fixed by 100 grams soil..........do.... | .0342 | .0152 | .0350 | .0268 | .0194 | .0231 |
| Per cent of nitrogen fixed | 18.1 | 8.03 | 18.5 | 14.2 | 10.2 | 12.2 |

| Percolates of 100 cc. each. | Soil No. 428. | | | | | |
|---|---|---|---|---|---|---|
| | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | |
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 100 | 66.2 | 154.5 | 44.9 | 86.1 | 140.7 | 81.5 |
| 200 | 88.2 | 116.9 | 103.6 | 108 | 128 | 112 |
| 300 | 89 | 112 | 93 | 110 | 122 | 107 |
| 500 | 109 | 109 | 103 | 123 | 154 | 116 |
| 700 | 120 | 136 | 107 | 118 | 133 | 112 |
| 900 | 103 | 116 | 110 | 149 | 146 | 122 |
| 1,100 | 90 | 139 | 114 | 148 | 134 | 144 |
| 1,300 | 118 | 157 | 147 | 176 | 162 | 145 |
| 1,500 | 147 | 172 | 159 | 187 | 172 | 178 |
| 1,700 | 147 | 172 | 147 | 172 | 172 | 172 |
| 1,900 | 172 | 187 | 172 | 187 | 187 | 187 |

SUMMARY.

| | | | | | | |
|---|---|---|---|---|---|---|
| Nitrogen added to 100 grams soil.........gram.. | 0.2064 | 0.2064 | 0.2064 | 0.2064 | 0.2064 | 0.2064 |
| Nitrogen fixed by 100 grams soil..........do.... | .0668 | .0322 | .0618 | .0358 | .0257 | .0437 |
| Per cent of nitrogen fixed | 32.4 | 15.6 | 29.9 | 17.3 | 12.5 | 21.2 |

The very concordant results in the above table add proof to the theory that the fixation of ammonium nitrogen and potash are strikingly similar. The fixing power of the soils was far less for the nitrogen of ammonium sulphate in mixtures than when used alone. It was found that the heat decreased the fixing power of the soil greatly, while chloroform had a very slight effect.

All solutions used in this series contained 172 parts per million nitrogen from ammonium sulphate.

### SODIUM NITRATE.

The following table gives the results of applying sodium nitrate in mixtures:

*Absorption of nitrogen from a solution of sodium nitrate in a mixed fertilizer.*

[Expressed in parts per million nitrogen in the percolate.]

| Percolates of 100 cc. each. | Soil No. 517. | | | Soil No. 428. | | |
|---|---|---|---|---|---|---|
| | Sodium nitrate, calcium phosphate, and potassium sulphate. | | | Sodium nitrate, calcium phosphate, and potassium sulphate. | | |
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 100 | 225 | 220 | 245 | 190 | 190 | 185 |
| 200 | 210 | 210 | 200 | 160 | 215 | 110 |
| 300 | 210 | 215 | 200 | 175 | 220 | 145 |
| 500 | 165 | 210 | 170 | 190 | 225 | 220 |
| 700 | 215 | 215 | 215 | 215 | 215 | 215 |
| SUMMARY. | | | | | | |
| Nitrogen added to 100 grams soil...gram.. | 0.1075 | 0.1075 | 0.1075 | 0.1075 | 0.1075 | 0.1075 |
| Nitrogen fixed by 100 grams soil....do.... | .0060 | .0010 | .0085 | .0145 | .0010 | .0200 |
| Per cent of nitrogen fixed | 5.6 | 0.9 | 7.9 | 13.5 | 0.9 | 18.6 |

The solutions used contained 215 parts per million nitrogen from nitrates, and, as was to be expected, the soils absorbed only extremely small amounts. The fixing power was shown to be very much less when this salt was applied in mixtures than when applied alone. the effect of heat was to decrease the fixing power, while the effect of chloroform was to produce a decided increase in fixing power. The latter is probably due to the sterilizing effect of the antiseptic upon the organisms present.

## REMOVAL OF ABSORBED SALTS.

At the conclusion of the preceding series distilled water was allowed to percolate through the tubes at the rate of 100 cubic centimeters in 24 hours. In every 100 cubic centimeters of the solution after the first thus obtained phosphoric acid, potash, and nitrogen were determined.

## REMOVAL OF ABSORBED PHOSPHATE.

In the following table will be found the results showing removal of absorbed phosphoric acid by distilled water from soil No. 517:

*Absorbed phosphoric acid removed from soil.*

[Expressed in parts per million $PO_4$ in the percolate.]

| Percolates of 100 cc. each. | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | | Sodium nitrate, calcium phosphate, and potassium sulphate. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 200 | 425 | 425 | 375 | 625 | 500 | 625 | 425 | 500 | 550 |
| 300 | 350 | 350 | 250 | 525 | 325 | 400 | 300 | 350 | 325 |
| 400 | 550 | 425 | 450 | 700 | 650 | 700 | 525 | 500 | 650 |
| 500 | 425 | 350 | 475 | 475 | 475 | 825 | 475 | 525 | ........ |
| 600 | 325 | 400 | 400 | 325 | 325 | 200 | 300 | 300 | 300 |
| 700 | 300 | 375 | 425 | 450 | 350 | 350 | 300 | 300 | 300 |
| 800 | 145 | 125 | 100 | 150 | 135 | 140 | 390 | 160 | 190 |
| 900 | 115 | 100 | 100 | 135 | 120 | 120 | 120 | 145 | 125 |
| 1,000 | 140 | 110 | 100 | 110 | 120 | 120 | 120 | 100 | 110 |
| 1,100 | 44 | 96 | 96 | 96 | 96 | 96 | 96 | 96 | 96 |
| 1,200 | 36 | 64 | 64 | 88 | 88 | 82 | 82 | 82 | 82 |
| SUMMARY. | | | | | | | | | |
| $PO_4$ fixed......gm.. | 0.7588 | 0.8548 | 0.6670 | 1.3982 | 1.278 | 1.0678 | 1.6134 | 1.2116 | 1.5014 |
| $PO_4$ removed..gm.. | .2855 | .2820 | .2835 | .3679 | .3184 | .3658 | .3133 | .3058 | .3008 |
| Per cent of $PO_4$ removed | 37.7 | 33.1 | 42.4 | 26.4 | 25. | 34.1 | 19.4 | 25.2 | 20.0 |

The above results show that the concentration of phosphate in the percolate decreased quite rapidly, approaching a constant. Apparently the potash salt was less strongly fixed as the precentage removed is greater than the calcium salt.

## REMOVAL OF ABSORBED POTASH.

In the following table will be found the results showing removal of absorbed potash by distilled water from soil No. 517:

*Removal of absorbed potash.*

[Expressed in parts per million K in the percolate.]

| Percolates of 100 cc. each. | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | | Sodium nitrate, calcium phosphate, and potassium sulphate. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 200 | 204 | 56 | 108 | 48 | 44 | 32 | 44 | 60 | 44 |
| 300 | 115 | 84 | 96 | 36 | 32 | 48 | 36 | 56 | 40 |
| 400 | 112 | 80 | 104 | 40 | 44 | 40 | 40 | 56 | 36 |
| 500 | 108 | 72 | 96 | 40 | 32 | 48 | 68 | 44 | 52 |
| 600 | 96 | 52 | 68 | 16 | 16 | 16 | 20 | 32 | 20 |
| 700 | 96 | 84 | 92 | 52 | 40 | 32 | 36 | 44 | 36 |
| 800 | 72 | 52 | 68 | 28 | 48 | ........ | ........ | ........ | 28 |
| 900 | 76 | 72 | 64 | 40 | 56 | 44 | 36 | 44 | 32 |
| 1,000 | 76 | 48 | 56 | 32 | 40 | 16 | 12 | 28 | 20 |
| 1,100 | 48 | 44 | 60 | 20 | 40 | 16 | 20 | 24 | 20 |
| 1,200 | 68 | 68 | 68 | 24 | 32 | 24 | 32 | 32 | 20 |
| SUMMARY. | | | | | | | | | |
| K removed....gm.. | 0.1072 | 0.0712 | 0.0880 | 0.0376 | 0.0424 | 0.0316 | 0.0344 | 0.0420 | 0.0348 |

The above table adds further proof toward indicating the small amounts of potash absorbed by this type of soil when added in mixtures. (See also p. 25.) There is little decrease in concentration of the percolate with regard to this element.

## REMOVAL OF ABSORBED NITROGEN.

In the following table will be found the results showing removal by distilled water of nitrogen absorbed from ammonium sulphate from soil No. 517:

*Removal of absorbed nitrogen.*

[Expressed in parts per million nitrogen in the percolate.]

| Percolates of 100 cc. each. | Ammonium sulphate, potassium phosphate, and potassium sulphate. | | | Ammonium sulphate, calcium phosphate, and potassium sulphate. | | |
|---|---|---|---|---|---|---|
| | Untreated. | Heated. | Chloroform. | Untreated. | Heated. | Chloroform. |
| 200 | 73 | 68 | 66 | 84 | 73 | 73 |
| 300 | 51 | 44 | 44 | 46 | 38 | 40 |
| 400 | 46 | 39 | 42 | 28 | 25 | 22 |
| 500 | 42 | 30 | 33 | 18 | 13 | 10 |
| 600 | 31 | 20 | 22 | 7 | 9 | ........ |
| 700 | 25 | 17 | 22 | 7 | 7 | 3 |
| 800 | 21 | 16 | 18 | 4 | 6 | 3 |
| 900 | 16 | 16 | 16 | 3 | 5 | 3 |
| 1,000 | 21 | 16 | 21 | 11 | 9 | 6 |
| 1,100 | 21 | 16 | 18 | 3 | 4 | 2 |
| 1,200 | 13 | 16 | 11 | 2 | 4 | 2 |

SUMMARY.

| | | | | | | |
|---|---|---|---|---|---|---|
| Nitrogen fixed.....gm.. | 0.0342 | 0.0152 | 0.0350 | 0.0268 | 0.0194 | 0.0231 |
| Nitrogen removed.....gm.. | .0360 | .0298 | .0313 | .0213 | .0193 | .0164 |
| Per cent of nitrogen removed | ........ | ........ | 89.5 | 79.6 | 99.4 | 71.0 |

The above table discloses the peculiar fact that practically all the nitrogen fixed by the soil from ammonium sulphate was removed by passing a liter of water through it. The concentration of the solution tended to decrease toward a constant value, as was the case with all the other elements of plant food.

## SUMMARY.

The data presented in the foregoing pages throw considerable light upon the behavior of fertilizer salts in Hawaiian soils. They show the variation in absorbing power with the variation in soil types and composition of fertilizer added. Hawaiian soils have resulted from the degradation of lava rocks, some of which have subsequently been changed through the addition of coral limestone or submergence by the sea. Therefore they would naturally be expected to be of a highly basic nature, and to yield a highly basic soil solution, depending upon the absorptive power of the soil. Some of the soils have been

subjected to dense tropical plant growth, resulting in the accumulation of high percentages of humus, which has been shown in the previous tables to affect materially the absorbing power. Furthermore, the data indicate that the concentration of the soil solution does not depend primarily upon the solubility of the mineral constituents, nor the amount of fertilizer added, but upon the absorbing power of the soil.

As was expected, the fixation of phosphoric acid was much higher than the other elements. This is due to the highly basic character of the soils, and especially to the large amounts of iron, aluminum, and titanium present. It has been found in recent pot experiments with this type of soil that crops respond most readily to soluble phosphates—namely, sodium phosphate and acid phosphate. There was considerable difference in the physical action of calcium and potassium phosphates, the latter having a decided deflocculating action upon the clay, while the calcium salt filtered through the soil column perfectly clear. This, coupled with the results of the pot experiments cited above, indicates that absorbed sodium and potassium phosphates are not insoluble, but diffuse more readily and are more easily available for the growing plants. This indicates that phosphate should be applied to Hawaiian soils in the soluble form, and the best time for application is just before planting, not on account of any danger of loss through drainage, but through the danger of a slight decrease in availability, due to reversion.

Apparently the controlling factors in the fixation of potash are the amounts of lime and magnesia present. This is very clearly shown in the above tables, and the soils used in the experiments were good examples with which to illustrate this point. The fixing power for this element, while not so strong as for the phosphoric acid, is quite marked. However, it should not be applied in too large quantities, nor too often, as it is quite readily leached from the soil by rains and irrigation.

The fixation of ammonium nitrogen, as already mentioned, is controlled by the same general factors which govern the absorption of potash. But the point of saturation is in most cases above that of the potash. However, it is not so strongly fixed and is leached out quite readily by the rains and drainage water. Some investigators claim that ammonia replaces the bases combined with the complex "humates," and, if so, this accounts for the soils in the first series having such a high fixing power both for potash and ammonium nitrogen, while the red clay soil was strikingly lower.

The power of the soil for fixing nitrate nitrogen is almost negligible, except in case of the highly organic soils. Apparently the organic

matter reacted with the nitrate solution, as the effect of this solution on the soil was quite marked.

The series showing the relation of the fixing power of soil and subsoil, and the effect of drying in the air, gave only slight differences. It was found, however, that phosphoric acid was fixed more strongly by the fresh soil, but there was scarcely any difference between the soil and subsoil. This is probably due to the fact that there is little, if any, difference in the mechanical condition of soil and subsoil in this red clay type, and also very little difference in chemical composition. The fixation of potash was higher in the air-dried soil, as previously explained, and higher in the subsoil than the soil. The ammonium nitrogen, strange to say, unlike the potash, was more strongly fixed by the fresh soil, which indicates the possibility of certain organisms affecting the fixation. The subsoil had a higher fixing power than the soil. There probably are also organisms acting as fixing agents for the nitrates, as the fresh samples had a higher fixing power than the air dry, while there was no difference in that of the soil and subsoil.

The most striking results are those obtained from the series in which a solution of mixed fertilizer was used. From the data at hand the conclusion is thought justified that the least waste is to be had by application of fertilizer salts singly rather than in mixtures. When the salts were applied singly there was a marked loss of potash, a decrease in amount of ammonium nitrogen fixed, a decrease in nitrate nitrogen, and a decrease in phosphates in case of the red clay, but scarcely any difference with the organic soil. However, there was no deflocculation of the soil when the salts were added in mixtures, except to a small extent in the mixtures which contained potassium phosphate. In this instance the percolates came through cloudy—that is, they contained deflocculated clay. On the other hand, the extracts in which the calcium salt was used were perfectly clear and colorless. Again, all the percolations proceeded quite rapidly, while several of the salts, the phosphates in particular, when used alone, would not allow a solution to pass through a column of soil. Solutions containing potassium phosphate percolated more slowly than those containing calcium phosphate.

The effect of heat and antiseptics was not very striking and the results were not very consistent. In one instance, a highly organic soil, heat decreased the fixing power for phosphoric acid, while in general it decreased the fixing power for potash, ammonium nitrogen, and nitrate nitrogen. The effect of chloroform on the fixation of the first three elements was negligible, while it increased the fixing power for nitrates.

The removal of the absorbed elements approached quite rapidly a constant in the case of the potash and ammonium salts, but more slowly in that of the phosphates. This was due to the excessive amounts of this constituent which had been added. By reference to tables on pages 5 and 8 it will be seen that when phosphates were added to the soil in light applications the concentration of the solution remained practically unchanged for an indefinite period.

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